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Mr. Arnab Lahiri
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1 February 2003

Dear Mr. Lahiri,

This letter is in response to the recently released Part 60 flight simulator qualification standard document of the FAA. First of all, you and your colleagues must be credited for taking the initiative to improve the standards applied to these and other training devices. It is always pleasing to see that the FAA standards continue to mate the training needs with the technologies available.

I would like in particular to address a few concerns about the motion system requirements in Part 60. In the attached document, I cover the basic issues and make some recommendations based on my own outlook and experience.

I hope that you will be in a position to make use of these comments in this and in future regulatory updates.

Sincerely,

Dr. Sunjoo K. Advani
Director Simulation & Training

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Comments on FAA Part 60 Simulator Qualification Document

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1 February 2003

1 General Comments on Motion in Part 60

In general, the Part 60 document reflects a rather traditional way of thinking with regard to the motion requirements. While I agree that it is valuable to place hard minimum limits on certain aspects, it must be clear to all parties – the aircraft manufacturer, the simulator builder, the user and the regulator – *why* these requirements are so solidly defined. From my point-of-view, it is clearly challenging to specify minimum limits, and I will try to explain why:

Motion feedback is beneficial for the control of an airplane and, unlike the visual information, it is always present (even when we close our eyes). As humans, we know that when we move, there will always be movement and, hence, motion. If we wish to control the simulated aircraft in the same way as we would the aircraft itself, then we must look at the interaction between the visual and the motion cues, since both of these create the perception of self motion. It is our own motion that we control, in fact, when we are flying the airplane.

Furthermore, the influence of motion has been shown to be task dependent as well. A target-following task, such as tracking the needle on a flight director, is far less motion-critical than, say, compensating for disturbances caused by turbulence. In the former case, the characteristics of the aircraft play a more important role than in the latter. Motion system latency influences pilot control behaviour in both cases.

Traditionally, motion cueing algorithms in flight simulators were designed to mimic the specific forces and angular accelerations available at the pilot's head position in the real aircraft. This is a nearly impossible goal, since it requires a motion workspace roughly the size of a football field. If, however, we (a) take the visual cues into account (which tend to reduce the required motion envelope because of their powerful influence), and (b) concern ourselves with the way the pilot uses the motion cues to control the airplane, then we will likely end up with a much better definition of the requirements. Clearly, this is not an easy task, and will require considerable effort in the coming period. In the end, it is an approach that promises a better transfer of skill-based behaviour from the simulator to the airplane.

Now, reviewing the current requirements, and with the foregoing in mind, it is difficult for me to endorse the specified motion excursion minima, and the way in which these are tested. I'll explain why:

First of all, the specified requirements for these excursions appear to be heuristically defined, and their definition seems contrary to all my previous indications. Furthermore, the following points should be raised:

1. The motion system test requirements state:

(11) Motion System Tests:

(a) The minimum excursions, accelerations, and velocities for pitch, roll, and yaw must be measurable about a single, common reference point and must be achieved by driving one degree of freedom at a time.

(b) The minimum excursions, accelerations, and velocities for heave, sway, and surge may be measured about different but identifiable reference points and must also be achieved by driving one degree of freedom at a time.

The allowance of measuring these motions about "different but identifiable reference points" negates the requirement itself. It would only make sense if both could be realized. In the end, the reference point should itself be close to the pilot's head if a similarity in the control strategy is desired (and it should be).

2. The excursion requirements state that the system must be capable of the following:

a. Minimum Excursion							
(1) Pitch	At least ±40°	N/A	X	X			An SOC is required for 3.a.(1) through (6). (Applicable to Initial evaluations only.) The "*" in the Simulator Level column applies if this DOF is used.
(2) Roll	At least ±40°	N/A	X	X			
(3) Yaw	At least ±45°	N/A	•	*			
(4) Heave	At least 40 inches total movement.	N/A	•	X			
(5) Sway	At least 45 inches total movement.	N/A	X	X			
(6) Surge	At least 50 inches total movement.	N/A	•	*			
(7) Pitch	At least ±50°	N/A			X	X	An SOC is required for 3.a.(7) through (12). (Applicable to Initial evaluations only.)
(8) Roll	At least ±50°	N/A			X	X	
(9) Yaw	At least ±50°	N/A			X	X	
(10)Heave	At least 68 inches total movement.	N/A			X	X	
(11)Sway	At least 90 inches total movement.	N/A			X	X	
(12)Surge	At least 68 inches total movement.	N/A			X	X	

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2 RECOMMENDATIONS

Based on prior analyses I have seen or have performed, the following recommendations are made:

2.1 Motion Excursion Requirements

- For all of the rotational requirements, it appears that the "±" symbol should be removed. There is absolutely no justification for such high rotational requirements, which severely limit the motion system design solutions. Recommendation: Remove all ± symbols preceding the numerical values for rotations.

- The requirement for Yaw tends to be the smallest for fixed-wing aircraft. The lateral accelerations caused by yaw, and the visual information, tend to keep the Yaw requirement to a minimum. Most motion systems are capable of ±30° in Yaw, and the current requirement of ±40° appears. Recommendation: Relax the Yaw requirement to ±30° in all cases.

- I cannot provide or cite any convincing argument either in favour of, nor against, the remaining translational displacement requirements. However, it should be noted that it is more important that the COUPLED motions are not severely limited by the choice of the motion-base mechanism. Motion cueing in a training environment tends to require many coupled effects; for example,

    - whether pitched up or not, the failure of an engine should allow similar lateral movement of the simulator in response to the engine failure transients
    - In steady-state operations in slipped conditions (e.g. following de-crab, or while flying with asymmetric thrust), the longitudinal and lateral motion envelope should allow similar movement as during normal flying conditions.

  The document states that, for example, in the Sway degree-of-freedom, a total movement of at least 90 inches is required. How much remains when a slight pitch angle is present is not known, and is hard to define.

  While the amount of motion required is dependent upon a number of factors (discussed above), it does not benefit the training if the displacement requirements are over-specified. Moreover, even if a simulator would be equipped with a motion-base with a specific envelope, one can not assume that the envelope will be exercised effectively.

Recommendation: Work towards a better definition of the required motion workspace, or envelope, that can indicate to the regulator the relative volume of this workspace, and not just its single-degree-of-freedom capabilities. I have developed an elliptical workspace description that I use to compare motion system cueing capability, and this appears to be a sound means of objectively defining the required motion space.

- The acceleration and velocity requirements are acceptable. These do not appear to be either too high for current motion systems, nor too low.

- From a pilot cueing and control point-of-view, it would, be better to specify all parameters not at a randomly-chosen point, but a reference point that is close (within a distance of 50 cm, for example) from the midpoint between the heads of the pilots. Then, all simulator footprints could be compared more objectively against each other.

2.2 Repeatability Tests

The purpose of these tests is to ensure that the motion system hardware and motion system software, in normal simulator operating mode, continues to perform as originally qualified. Hence, performance changed from the original baseline can be readily identified.

- *Under the heading "Motion Cue Repeatability" (Page 5, Attachment 2 to Appendix A to Part 60, Simulator Objective Tests), there is a spelling error: "at lease" should read "at least".*

- *The use of the test input signals appears to be intended to exercise the motion system through "approximately 2/3 of the maximum displacement capability in each axis". Dependent upon the aircraft characteristics, the location of the pilot with respect to the motion system upper frame, the motion system geometry, and the tuning parameters on any given motion system, the outputs will vary. Therefore, this is not a significant test. Supposing we know that the required Yaw is small even though this generates excellent pilot behaviour. Is it then necessary to artificially increase the Yaw gains in order to qualify the system? I fully understand the legitimate goals of trying to specify such requirements, however, I cannot imagine how this will yield an improvement in training value. Recommendations: Remove the currently-formulated Motion Cue Repeatability requirement, and instead utilize (as soon as possible) the concept of the Motion Cue Performance Signature as proposed by the ICAO working group, and already implemented by the JAR STD-1A.*

2.3 Frequency Response

- *While the specification of maximum 45 degrees phase lag at 4 Hertz is aimed at ensuring good motion system mechanical performance, it is a considerably higher requirement than many modern motion systems can generate, and may unnecessarily increase the cost of motion cueing systems. Recommendation: Relax this requirement to 4 Hertz at 90 degrees.*

- *Secondly, the more important area in terms of piloting control is actually at lower frequencies. It would be valuable, therefore, to say that below 4 Hertz, the magnitude and phase of the system should be smooth, such that on the plots showing these quantities there are no peaks below 4 Hz.*

2.4 Other

I did not see a requirement for motion characteristic vibrations. The ICAO motion working group came with the following three recommendations:

1) The recorded test results for characteristic buffets must allow the comparison of relative amplitude versus frequency.

2) For atmospheric disturbance testing, general purpose disturbance models that approximate demonstrable flight test data are acceptable.

3) Principally, the simulator results should exhibit the overall appearance and trends of the airplane plots, with at least some of the frequency "spikes" being present within 1 or 2 Hz of the airplane data.

Recommendation: Incorporate similar requirements in the FAA standards as well.

3 Conclusions

The Part 60 document indeed represents a major potential improvement in the characteristics of the simulators that will be qualified against it. The aforementioned suggestions will only help make the document more realistic in terms of cost-benefits, and better tuned to recent knowledge in human motion perception and control.

Clearly, there can still be much improved in flight simulation, and the area of motion cueing is no exception. ADSE would be very willing to work with the FAA to better define these requirements in future training standards.